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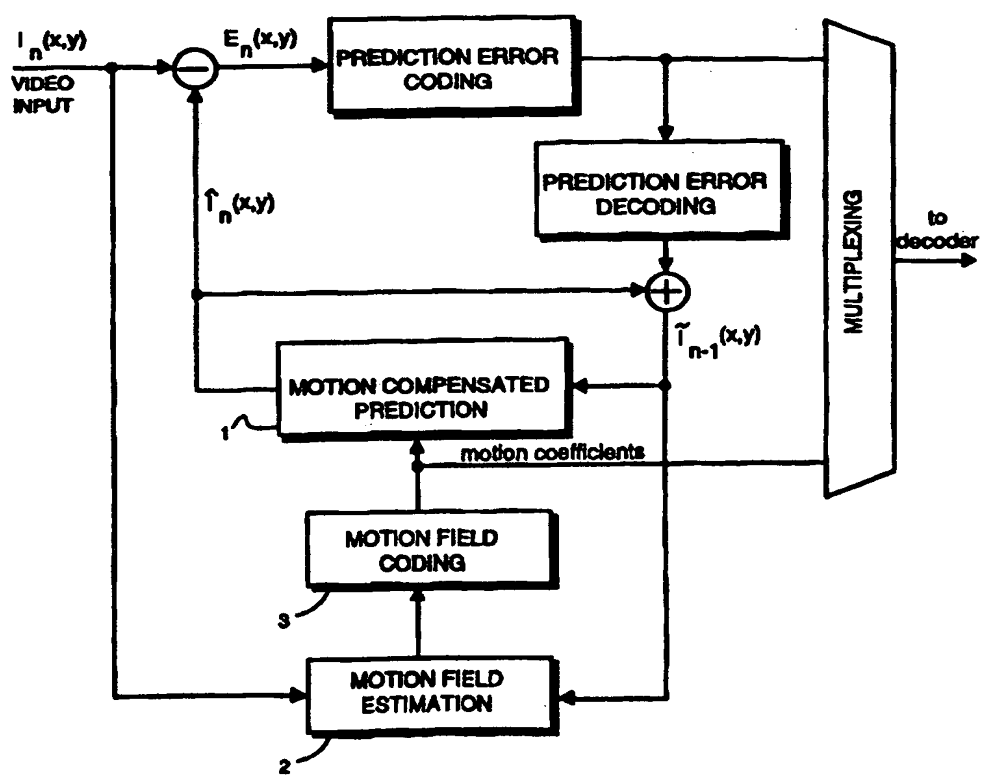
(54) Title: MOTION VECTOR FIELD CODING

(57) Abstract

A video codec includes a motion field coder for minimizing the number of motion coefficients of a motion vector field. In the coder, a first block includes means for forming a new matrix representation of the motion vector field. The new coded motion vector field is linear. A second main block includes means for merging pairs of adjacent segments if the combined segment area can be predicted using a common motion field. Merging information is transmitted to a decoder. A third main block includes means for removing motion field basis functions. After each removing step, the squared prediction error is calculated and removing is continued until the chance of the error is not acceptable. Final motion coefficients are calculated by solving a linear matrix equation. As a result, reduced number of motion coefficients of each segment are obtained. The motion coefficients are transmitted to the decoder.



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Motion vector field coding

FIELD OF THE INVENTION

The present invention generally relates to video compression. More precisely, the invention relates to a method of coding an estimated motion field and for generating motion information in a video sequence.

BACKGROUND OF THE INVENTION

The motion compensated prediction is a key element of majority of video coding schemes. Figure 1 is a schematic diagram of an encoder for compression of video sequences using motion compensation. Essential elements in the encoder are a motion compensated prediction block 1, a motion estimator 2 and a motion field coder 3. The operating principle of the motion compensating video coders is to compress the prediction error $E_n(x,y)$, which is a difference between the incoming frame $I_n(x,y)$ being coded called the current frame and a prediction frame $\hat{I}_n(x,y)$, wherein:

$$E_n(x,y) = I_n(x,y) - \hat{I}_n(x,y) \tag{1}$$

The prediction frame $\hat{I}_n(x,y)$ is constructed by the motion compensated prediction block 1 and is built using pixel values of the previous, or some other already coded frame denoted $\tilde{I}_{n-1}(x,y)$, called a reference frame, and the motion vectors of pixels between the current frame and the reference frame. Motion vectors are calculated by the motion field estimators 2 and the resulting vector field is then coded in some way before applying to the predictor block 1. The prediction frame is then:

$$\hat{I}_n(x,y) = \tilde{I}_{n-1}[x + \Delta x(x,y), y + \Delta y(x,y)] \tag{2}$$

The pair of numbers $[x+\Delta x(x,y), y+\Delta y(x,y)]$ is called the motion vector of pixel in location (x, y) in the current frame, whereas $\Delta x(x,y)$ and $\Delta y(x,y)$ are the values of horizontal and vertical displacement of this pixel. Set of motion vectors of all pixels in the current frame $I_n(x,y)$ is called motion vector field. The coded motion vector field is also transmitted as motion infromation to the decoder.

In the decoder, fig 2, pixels of the current frame $I_n(x,y)$ are reconstructed by finding the pixels' predictions $\hat{I}_n(x,y)$ in the reference frame $\tilde{I}_{n-1}(x,y)$. The motion compensated prediction block 21 generates the prediction frame using the received motion information and the reference frame $\tilde{I}_{n-1}(x,y)$ (in this picture the reference frame is the same as the current frame). In the prediction error decoder 22 decoded prediction error $E_n(x,y)$ is then added with the prediction frame, the result being the original current frame I_n.

The general object of the motion compensated (MC) prediction is to minimize amount of information which needs to be transmitted to the decoder. It should minimize the amount of prediction error measured, e.g., as the energy of $E_n(x,y)$, and minimize the amount of information needed to represent motion vector field.

The document H.Nguen, E.Dubois, "Representation of motion information for image coding". Proc. Picture Coding Symposium '90, Cambridge, Massachusetts, March 26-18, 1990, pages 841-845, gives a review of motion field coding techniques.As a rule of the thumb reduction of prediction error requires more sophisticated motion field, i.e., more bits must be spent on its encoding. Therefore the overall goal of the video encoding is to encode as compactly as possible the motion vector field keeping at the same time the measure of prediction error as low as possible.

The motion field estimation block 1, fig. 1, calculates motion vectors of all the pixels of a given segment which minimize some measure of prediction error in this segment, for example square prediction error. Motion field estimation techniques differ both in the model of the motion field and in the algorithm for minimisation of the chosen measure of prediction error.

Due to very large number of pixels in the frame it is not efficient to transmit a separate motion vector for each pixel. Instead, in most of the video coding schemes the current frame is divided into larger image segments so that all motion vectors of the segment can be described by few parameters. Image segments can be square blocks, e.g. 16x 16 pixels blocks are used in codecs in accordance with international standard ISO/IEC MPEG-1 or ITU-T

H.261, or they can comprise of completely arbitrarily shaped regions obtained for instance by a segmentation algorithm. In practice segments include at least few tens of pixels.

In order to compactly represent the motion vectors of the pixels in the segment it is desireable that their values are described by a function of few parameters. Such function is called motion vector field model. A known group of models are linear motion models, in which motion vectors are linear combinations of motion field basis functions. In such models the motion vectors of image segments are described by a general formula:

$$\begin{aligned}\Delta x(x,y) &= \sum_{i=1}^{N} c_i f_i(x,y) \\ \Delta y(x,y) &= \sum_{i=N+1}^{N+M} c_i f_i(x,y)\end{aligned} \qquad (3)$$

where parameters c_i are called motion coefficients and are transmitted to the decoder. Functions $f_i(x,y)$ are called motion field basis functions which are fixed and known both to encoder and decoder.

The problem when using the linear motion model having the above described formula is how to minimize the number of motion coefficients c_i which are send to the decoder, preserving at the same time as low measure of prediction error $E_n(x,y)$ as possible. This process is performed in the encoder by the motion field coding block 3, see fig. 1. It is performed after computationally very complex motion field estimation which is accomplished by the block 2. It is therefore crucial that motion field coding is computationally simple so that it does not impose additional burden on the encoder.

The total number of motion coefficients which needs to be sent to the decoder depends both on number of segments in the image and number of motion coefficients per segment. Therefore, there is at least two ways to reduce the total number of motion coefficients.

The first way is to reduce the number of segments by combining (merging) together those segments which can be predicted with a common motion vector field without causing a large increase of prediction error. The number of segments in the frame can be reduced because very often the

adjacent, i.e. neighbouring, segments can be predicted well with the same set of motion coefficients. Process of combining such segments is called motion assisted merging.

The second way is to select for each segment a motion model which allows achieving satisfactorily low prediction error with as few coefficients as possible. Since the amount and the complexity of the motion varies between frames and between segments it is not efficient to use always all $N+M$ motion coefficients per segment. It is necessary to find out for every segment what is the minimum number of motion coefficients which allows to achieve satisfactorily low prediction error. The process of such adaptive selection of coefficients is called motion coefficient removal.

Figure 3 shows a frame divided into segments. The prior art techniques for motion coefficient coding include several techniques for motion assisted merging. After motion vectors of all the segments have been estimated, the motion assisted merging is performed. It is done by considering every pair of adjacent segments S_i and S_j with their respective motion coefficients $\mathbf{c}_i$ and $\mathbf{c}_j$. Area of combined segments S_i and S_j is denoted S_{ij}. If the area S_{ij} can be predicted with one set of motion coefficients $\mathbf{c}_{ij}$ without causing excessive increase of prediction error over the error resulting from separate predictions of S_i and S_j, then S_i and S_j are merged. The methods for motion assisted merging differ essentially in the way of finding a single set of motion coefficients $\mathbf{c}_{ij}$ which allow a good prediction of segments combined together.

One method is known as merging by exhaustive motion estimation. This method estimates "from scratch" a new set of motion parameters $\mathbf{c}_{ij}$ for every pair of adjacent segments S_i and S_j. If the prediction error for S_{ij} is not excessively increased then the segments S_i and S_j are merged. Although this method can very well select the segments which can be merged it is not feasible for implementation because it would increase the complexity of the encoder typically by several orders of magnitude.

Another method is known as merging by motion field extension. This method tests whether area of S_{ij} can be predicted using either motion parameters $\mathbf{c}_i$ or $\mathbf{c}_j$ without an excessive increase of the prediction error. This method is characterised by very low computational complexity because it does not require any new motion estimation. However, it fails to merge segments very often because motion compensation with coefficients calculated for one segment very rarely predicts well also the adjacent segments.

Still another method is known as merging by motion field fitting. In this method the motion coefficients $\mathbf{c}_{ij}$ are calculated by the method of approximation. This is done by evaluating few motion vectors in each of the segments. Some motion vectors in segments S_i and S_j are depicted in figure 3. The motion field for the segment S_{ij} is done by fitting a common motion vector field through these vectors using some known fitting method. The disadvantage of the method is that motion field obtained by fitting is not precise enough and often leads to unacceptable increase of prediction error.

Methods for performing motion estimation with different models and selecting the most suitable one are proposed in the documents H. Nicolas and C. Labit, "Region-based motion estimation using deterministic relaxation schemes for image sequence coding," Proc. 1994 International Conference on Acoustics, Speech and Signal Processing, pp. III265-268 and P. Cicconi and H. Nicolas, "Efficient region-based motion estimation and symmetry oriented segmentation for image sequence coding," IEEE Tran. on Circuits and Systems for Video Technology, Vol. 4, No. 3, June 1994, pp. 357-364. The methods try to adapt the motion model depending on complexity of the motion by performing motion estimation with different models and selecting the most suitable one. The main disadvantage of these methods is their high computational complexity and low amount of different motion field models which can be tested in practice.

None of afore described methods alone solves the problem how to minimize the number of motion coefficients c_i which are send to the decoder,

preserving at the same time as low measure of prediction error $E_n(x,y)$ as possible.

SUMMARY OF THE INVENTION

An objective of the present invention is to create a motion field coder which reduces the amount of motion field vector information produced by some known motion estimator by large factor without causing large increase of prediction error. The complexity of the motion field coder should be low for allowing practical implementation on available signal processors or general purpose microprocessors.

In accordance with the invention, the motion field coder includes three main blocks.

The first main block is called a QR motion analyzer. Its task is to find a new representation of the inputted motion field produced by the motion field estimator. This new representation is applied to the second main block. Operations in this first main block include a plurality of steps comprising matrix operations: In the first step the prediction frame is linearized using some known approximation method so that the prediction frame becomes linear with respect to motion vectors. In the second step a matrix E_i and a matrix y_i are constructed for minimisation of the square prediction error. In the third step the well known QR factorization algorithm is used to decompose the matrix E_i into a product of two matrices Q_i and R_i. In addition, an auxiliary vector z_i is calculated from the factor matrix Q_i and the matrix y_i. Part of the matrix R_i and the auxiliary vector z_i are applied to the second main block.

The secod main block called a segment merging block performs merging operation for pairs of adjacent segments by finding whether their combined area can be predicted using a common motion field. In the matrix operations a matrix equation is firstly formed, thereafter the factor matrices are processed by using known matrix computation methods. The result is a matrix equation, where one matrix includes terms on the basis of which it is easy to calculate the sqare prediction error in the area of the merged segments. If the change

of the square prediction error is acceptable according to a chosen criterion the the segments are merged.

After all pairs of segments are considered the output of the segment merging block is :

i. a new division of the image with reduced number of segments,

ii. for each new segment the block outputs matrix $\mathbf{R}^1_{ij}$, vector $\mathbf{z}^1_{ij}$,

iii. merging information which is sent to the decoder and helps the decoder to identify segments which were merged.

The third main block is called a coefficient removal block. The block receives as the input new division of the current frame into segments and for every segment it receives matrices $\mathbf{R}^1_k$, $\mathbf{z}^1_k$, and $\mathbf{c}_k$ produced by the segment merging block. Motion vectors of every segment are represented by a number of motion coefficients. The motion coefficient removal block determines for each of the segments if it is possible to simplify the motion field model, without excessive increase of prediction error. Some basis functions are removed from the motion model, wherein less coefficients are required to describe such a simplified motion field model.

The operations in this third main block are matrix operations, in which the matrix equation is firstly modified by removing one column and row of the factor matrices, then the matrix equation is triangularized. Removal one column and row correspods to removal one basis function from the motion model. The change of the square prediction error for the segment caused by removal of one basis function is equal to the square of one term in equation.

If the change of the prediction error is acceptable according to a chosen criterion than one coefficient is removed from the coefficient set. More coefficients for the segment can be reduced further repeating these matrix operations. After sufficient amount of coefficients has been removed final motion coefficients for the segment are calculated by solving the resulting linear equation. The equation can be solved using one of well known algorithms, e.g., backsubstitution.

This third main block outputs for every processed segment selection information which tells which basis functions were removed from motion field

model. Additionally it outputs new motion coefficients corresponding to the remaining basis functions. Both selection information and motion coefficients are transmitted to the decoder.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic diagram of a known encoder;

Fig. 2 is a schematic diagram of a known decoder;

Fig. 3 depicts adjacent segments for merging;

Fig. 4 illustrates merging by motion field approximation;

Fig. 5 is the motion field coder according to the invention;

Fig. 6 is a schematic diagram of QR motion analyser.

DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENT

Fig. 5 illustrates the motion field encoder according to the invention. It corresponds to the block 3 in fig. 1 but it has as inputs also the reference frame and the current frame. The third input to this block is the motion vector field $[\Delta x(\cdot), \Delta y(\cdot)]$ produced by motion field estimation block 2, fig. 1.

If we imagine, that the output of the video encoder is the compressed frame divided into segments and each of the segments is accompanied by motion coefficients, then for a segment S_i which consists of P pixels with coordinates (x_i, y_i), $i = 1,2,\ldots,P$, the task of the motion field coder is to find the motion coefficients $\tilde{\mathbf{c}} = (\tilde{c}_1, \tilde{c}_2, \ldots, \tilde{c}_{N+M})$ of a compressed motion vector field $[\tilde{\Delta}x(\cdot), \tilde{\Delta}y(\cdot)]$ where the motion vectors are described by a linear motion model, the field being of the form:

$$\tilde{\Delta}x(x,y) = \sum_{i=1}^{N} \tilde{c}_i f_i(x,y) \qquad (4a)$$

$$\tilde{\Delta}y(x,y) = \sum_{i=N+1}^{N+M} \tilde{c}_i f_i(x,y) \qquad (4b)$$

such that it minimizes square prediction error:

$$\sum_{i=1}^{P} (I_n(x_i, y_i) - \tilde{I}_{n-1}(x_i + \tilde{\Delta}x(x_i, y_i), y_i + \tilde{\Delta}y(x_i, y_i)))^2. \qquad (5)$$

To fulfill said task, the motion field encoder consists of three main building blocks which are the QR motion analyser block, the segment merging block and the motion coefficient removal block. The segment merging block and the motion coefficient removal block reduce the amount of motion information which results in increase of the square prediction error.

The objective of the QR motion analyzer is to find a new representation of the motion field. This new representation is used later in the other two blocks for a fast and flexible finding of motion coefficients for merged segments and for coefficient removal.

The operation of QR Motion Analyzer consists of following steps:

Step 1 is linearization of error. In this step the prediction frame $\tilde{I}_{n-1}(\cdot)$ in equation (7) is approximated using some known approximation method so that it becomes linear with respect to $\left[\tilde{\Delta}x(\cdot),\tilde{\Delta}y(\cdot)\right]$. Then elements under sum in the formula (5) become linear combinations of coefficients c_i

$$\sum_{j=1}^{P}(e_{j,1}\tilde{c}_1+e_{j,2}\tilde{c}_2+\cdots+e_{j,N+M}\tilde{c}_{N+M}-y_j)^2 \qquad (6)$$

Step 2 is construction of matrices. It is based on the fact that minimisation of the formula (6) is fully equivalent to minimisation of the matrix expression $(\mathbf{E}_i\tilde{\mathbf{c}}_i-\mathbf{y}_i)^T(\mathbf{E}_i\tilde{\mathbf{c}}_i-\mathbf{y}_i)$, where $\mathbf{E}_i$ and $\mathbf{y}_i$ are:

$$\mathbf{E}_i=\begin{bmatrix} e_{1,1} & e_{1,2} & \cdots & e_{1,N+M} \\ e_{2,1} & e_{2,2} & \cdots & e_{2,N+M} \\ \vdots & \vdots & \vdots & \vdots \\ e_{P,1} & e_{P,2} & \cdots & e_{P,N+M} \end{bmatrix}, \qquad \mathbf{y}_i=\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_P \end{bmatrix} \qquad (7)$$

Step 3 is QR Factorization. The well known QR factorization algorithm is described in the document G. H. Golub and C. van Loan, " Matrix computation" 2'nd edition, The Johns Hopkins University Press, 1989. This algorithm is used to decompose $\mathbf{E}_i$ into a product of two matrices

$$\mathbf{E}_i=\mathbf{Q}_i\mathbf{R}_i \qquad (8)$$

In this step is also calculated an auxiliary vector $\mathbf{z}_i$ where

$$\mathbf{z}_i=\mathbf{Q}^T{}_i\mathbf{y}_i \qquad (9)$$

In step 4 the output of the QR motion analyzer block is calulated. The output comprises of a matrix $\mathbf{R}_i^1$ consisting of N+M first rows of matrix $\mathbf{R}_i$ and a vector $\mathbf{z}^1{}_i$ consisting of first $N+M$ elements of $\mathbf{z}_i$.

In the segment merging block merging operation is performed for pairs of adjacent segments S_i and S_j, see fig. 4, by finding whether their combined area S_{ij} can be predicted using a common motion field described by motion coefficients $\mathbf{c}_{ij}$. Merging operation consists of the following steps:

Step 1 comprises matrix calculation. This invention utilizes a previously unknown property that motion coefficients $\mathbf{c}_{ij}$ can be found by solving the system of linear equations:

$$\begin{bmatrix} \mathbf{R}^1{}_i \\ \mathbf{R}^1{}_j \end{bmatrix} \mathbf{c}_{ij} = \begin{bmatrix} \mathbf{z}^1{}_i \\ \mathbf{z}^1{}_j \end{bmatrix} \tag{10}$$

where $\mathbf{R}^1{}_i$, $\mathbf{z}^1{}_i$ and $\mathbf{R}^1{}_j$, $\mathbf{z}^1{}_j$ are already produced by the QR analyzer block for segments S_i and S_j respectively.

Step 2 comprises triangularization of the matrices obtained in the step 1. Matrices $\mathbf{R}^1{}_i$, $\mathbf{R}^1{}_j$ are upper triangular and the system in equation (10) has according to the teaching of the afore mentioned documet the form:

$$\begin{bmatrix} \times & \times & \times & \cdots & \times \\ & \times & \times & \cdots & \times \\ & & \times & \cdots & \times \\ & & & \ddots & \vdots \\ & & & & \times \\ \times & \times & \times & \cdots & \times \\ & \times & \times & \cdots & \times \\ & & \times & \cdots & \times \\ & & & \ddots & \vdots \\ & & & & \times \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ \vdots \\ c_{N+M} \end{bmatrix} = \begin{bmatrix} z^i{}_1 \\ z^i{}_2 \\ z^i{}_3 \\ \vdots \\ z^i{}_{N+M} \\ z^j{}_1 \\ z^j{}_2 \\ z^j{}_3 \\ \vdots \\ z^j{}_{N+M} \end{bmatrix} \tag{11}$$

where symbol $\times$ denotes a nonzero element. According to the teaching of the afore mentioned documet, the system is triangularized by applying a series of multiplications of rows by scalars followed by additions of the rows, i.e., it is converted to the form:

$$\begin{bmatrix} r_{1,1} & r_{1,2} & r_{1,3} & \cdots & r_{1,N+M} \\ 0 & r_{2,2} & r_{2,3} & \cdots & r_{2,N+M} \\ 0 & 0 & r_{3,3} & \cdots & r_{3,N+M} \\ 0 & 0 & 0 & \ddots & \vdots \\ 0 & 0 & 0 & 0 & r_{N+M,N+M} \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ \vdots \\ c_{N+M} \end{bmatrix} = \begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ \vdots \\ z_{N+M} \\ q_1 \\ q_2 \\ q_3 \\ \vdots \\ q_{N+M} \end{bmatrix} \qquad (12)$$

In the step 3 merging error is evaluated. The change of the square prediction error ΔE_{ij} in the area S_{ij} caused by merging of segments S_i and S_j is calculated according to the teaching of the afore mentioned documet, wherein

$$\Delta E_{ij} = \sum_{k=1}^{N+M} q^2_k \qquad (13)$$

Finally, in the step 4 the segments are merged if the change of square prediction error in the formula (13) is acceptable according to a chosen criterion. For the resulting new segment S_{ij} matrix $\mathbf{R}^1_{ij}$ and vector $\mathbf{z}^1_{ij}$ are built by taking first N+M rows of the system in equation (12), i.e., are given by formula:

$$\mathbf{R}^1_{ij} = \begin{bmatrix} r_{1,1} & r_{1,2} & r_{1,3} & \cdots & r_{1,N+M} \\ & r_{2,2} & r_{2,3} & \cdots & r_{2,N+M} \\ & & r_{3,3} & \cdots & r_{3,N+M} \\ & & & \ddots & \vdots \\ & & & & r_{N+M,N+M} \end{bmatrix}, \quad \mathbf{z}^1_{ij} = \begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ \vdots \\ z_{N+M} \end{bmatrix} \qquad (14)$$

After all pairs of segments of the frame are considered the output of the segment merging block is obtained. The output comprises of three kind of information. Firstly, it gives a new division of the image with reduced number of segments. Secondly, it gives for each new segment the block outputs matrix $\mathbf{R}^1_{ij}$, vector $\mathbf{z}^1_{ij}$ .Thirdly, it gives merging information which is sent to the decoder and helps the decoder to identify segments which were merged.

The motion coefficients $\mathbf{c}_{ij} = (c_1, c_2, \ldots c_{N+M})$ for the segment S_{ij} could be now calculated by solving the system of equations $\mathbf{R}^1{}_{ij}\mathbf{c}_{ij} = \mathbf{z}^1{}_{ij}$ but their calculation is not necessary if the next block, the coefficient removal block is used.

We consider now operation of the coefficient removal block. The block receives as the input new division of the current frame into segments and for every segment S_k it receives matrices $\mathbf{R}^1{}_k$, $\mathbf{z}^1{}_k$, and $\mathbf{c}_k$ produced previously by the segment merging block. Motion vectors of every segment is represented by $N+M$ motion coefficients.

The motion coefficient removal block determines for a given segment S_k if it is possible to simplify the motion field model, without excessively increase of prediction error. Simplified motion field model is obtained when some basis functions are removed from the model in equations (3) described in the background art of this application. Less coefficients are required to describe such a simplified motion field model.

The following procedure is performed for segments in order to find out whether i'th basis function (and i'th coefficient) can be removed from the motion field model:

Step 1 includes matrix modification, where system of linear equations

$$\mathbf{R}^1{}_k\mathbf{c}_k = \mathbf{z}^1{}_k \qquad (15)$$

is modified by removing i'th column from $\mathbf{R}^1{}_k$ and i'th element are from $\mathbf{c}_k$.

Step 2 includes matrix triangularization, where the system in equation (15) is triangularized in the known manner by applying a series of multiplications of rows by scalars followed by additions of the rows, i.e., it is converted to the form:

$$\begin{bmatrix} r_{1,1} & r_{1,2} & r_{1,3} & \cdots & r_{1,N+M-1} \\ 0 & r_{2,2} & r_{2,3} & \cdots & r_{2,N+M-1} \\ 0 & 0 & r_{3,3} & \cdots & r_{3,N+M-1} \\ 0 & 0 & 0 & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & r_{N+M-1,N+M-1} \\ 0 & 0 & 0 & \cdots & 0 \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ \vdots \\ c_{N+M-1} \end{bmatrix} = \begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ \vdots \\ z_{N+M-1} \\ q_i \end{bmatrix} \qquad (16)$$

Step 3 includes error evaluation. The change of the square prediction error for the segment caused by removal of i'th coefficient is simply equal to the term q^2_i in equation (16).

Step 4 includes removal of coefficients. If the change of the prediction error is acceptable according to a chosen criterion than the coefficient c_i is removed from the coefficient set. The new number of coefficients is now N+M-1. Matrix $\mathbf{R}^1{}_k$ and vector $\mathbf{z}^1{}_k$ are modified to form:

$$\mathbf{R}^1{}_k = \begin{bmatrix} r_{1,1} & r_{1,2} & r_{1,3} & \cdots & r_{1,N+M-1} \\ & r_{2,2} & r_{2,3} & \cdots & r_{2,N+M-1} \\ & & r_{3,3} & \cdots & r_{3,N+M-1} \\ & & & \ddots & \vdots \\ & & & & r_{N+M-1,N+M-1} \end{bmatrix}, \qquad \mathbf{z}^1{}_k = \begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ \vdots \\ z_{N+M-1} \end{bmatrix} \tag{17}$$

Number of coefficients for the segment can be reduced further by using matrices (17) in the equation (15) and repeating the steps 1-4.

Step 5 includes coefficient calculation. After sufficient amount of coefficients has been removed, this step is started. In this step final motion coefficients for a segment S_k are calculated by solving the system of linear equations:

$$\mathbf{R}^1{}_k \mathbf{c}_k = \mathbf{z}^1{}_k \tag{18}$$

where matrix $\mathbf{R}^1{}_k$ and vector $\mathbf{z}^1{}_k$ are the result of the previous steps 1-4. The equation can be solved using one of well known algorithms, e.g., backsubstitution.

The motion coefficient removal block outputs for every processed segment selection information which tells to the decoder which basis functions were removed from motion field model. Additionally it outputs new motion coefficients corresponding to the remaining basis functions. Both selection information and motion coefficients are transmitted to the decoder.

As a result of all of the steps in all of the blocks, the motion field coder according to the invention produces merging information telling to the decoder which segments are merged, selection information telling to the decoder which basis functions are removed and motion coefficient information.

The main advantage of the present invention over prior art solutions is its ability to reduce the amount of motion information by large factor without causing large increase of prediction error. Additionally the complexity of the overall system is low which allows practical implementation on available signal processors or general purpose microprocessors.

The segment merging block has a unique ability of finding motion vectors of combined segments from given motion vectors estimated for separate segments. It can be proven that the motion vectors it produces are in fact optimal in terms of keeping minimal square error for the combined segment. This explains the ability of this block to dramatically reduce the number of segments with only very modest increase of square prediction error.

The motion coefficient removal block is a very powerful tool for instantaneous adaptation of the motion model to the actual amount and type of motion in the video scene. This block can easily test the result of prediction (value of square prediction error for a segment) with a very large number of models, e.g., with all possible combinations of motion field basis functions. No other known method has this amount of flexibility. A strong advantage of this scheme is that it does not need to repeat process of motion estimation hence is computationally simple.

By using motion estimation followed by QR motion analyzer the motion field coder can find new motion coefficients for any desired combination of image segments or any desired model of the motion field in the segment by solving very simple systems of linear equations.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In the preferred implementation quadratic polynomial motion vector field model with 12 coefficients is used:

$$\Delta x(x,y) = c_1 + c_2 x + c_3 y + c_4 xy + c_5 x^2 + c_6 y^2$$
$$\Delta y(x,y) = c_7 + c_8 x + c_9 y + c_{10} xy + c_{11} x^2 + c_{12} y^2$$

This model in practice can handle very well even very complex motion in video sequences and yields good prediction results.

In the QR motion analyzer block, linearization in the step 1 is done by using Taylor expansion of $\tilde{I}_{n-1}(\cdot)$ at every pixel (x_i, y_i) where $i = 1,2,\ldots,P$ around points:

$$x_i' = x_i + \Delta x(x_i, y_i)$$
$$y_i' = y_i + \Delta y(x_i, y_i)$$

Using property that $\sum a^2 = \sum (-a)^2$, the prediction error is then

$$\sum_{i=1}^{P} (\tilde{I}_{n-1}(x_i', y_i') + (\tilde{\Delta}x(x_i, y_i) - \Delta x(x_i, y_i))G_x(x_i', y_i') + (\tilde{\Delta}y(x_i, y_i) - \Delta y(x_i, y_i))G_y(x_i', y_i') - I_n(x_i, y_i))^2$$

Auxiliary values $g_j(x, y)$ are calculated using formula:

$$g_j(x_i, y_i) = \begin{cases} f_j(x_i, y_i)G_x(x_i, y_i) & \text{when } j = 1,2,\ldots,N \\ f_j(x_i, y_i)G_y(x_i, y_i) & \text{when } j = N+1, N+2,\ldots, N+M \end{cases}$$

where function $f_j(x_i,y_i)$ is basis function as defined in the equations (4a) and (4b).

Matrix $\mathbf{E}$ and vector $\mathbf{y}$ in equation (9) are build using formulas:

$$\mathbf{E} = \begin{bmatrix} g_1(x_1, y_1) & g_2(x_1, y_1) & \cdots & g_{N+M}(x_1, y_1) \\ g_1(x_2, y_2) & g_2(x_2, y_2) & \cdots & g_{N+M}(x_2, y_2) \\ \vdots & \vdots & \vdots & \vdots \\ g_1(x_P, y_P) & g_2(x_P, y_P) & \cdots & g_{N+M}(x_P, y_P) \end{bmatrix},$$

$$\mathbf{y} = \begin{bmatrix} I_n(x_1, y_1) - \tilde{I}_{n-1}(x_1', y_1') + G_x(x_1', y_1')\Delta x(x_1, y_1) + G_y(x_1', y_1')\Delta y(x_1, y_1) \\ I_n(x_2, y_2) - \tilde{I}_{n-1}(x_2', y_2') + G_x(x_2', y_2')\Delta x(x_2, y_2) + G_y(x_2', y_2')\Delta y(x_2, y_2) \\ \vdots \\ I_n(x_P, y_P) - \tilde{I}_{n-1}(x_P', y_P') + G_x(x_P', y_P')\Delta x(x_P, y_P) + G_y(x_P', y_P')\Delta y(x_P, y_P) \end{bmatrix}.$$

$G_x(x, y)$ and $G_y(x, y)$ are values of the horizontal and vertical gradient of the reference frame $\tilde{I}_{n-1}(x, y)$ calculated using following formula:

$$G_x(x, y) = \tilde{I}_{n-1}(x+1, y) - \tilde{I}_{n-1}(x-1, y),$$
$$G_y(x, y) = \tilde{I}_{n-1}(x, y+1) - \tilde{I}_{n-1}(x, y-1).$$

Figure 6 shows a schematic diagram of QR Motion Analyzer. Row selection block selects only N+M first rows of the input matrix.

In the segment merging block following strategy for segment merging is used:

a. a threshold T is selected which corresponds to allowed increase of square prediction error in whole frame.

b. for all pairs of adjacent segments ΔE_{ij} is calculated using equation (13).

c. pair of segments with smallest ΔE_{ij} is merged.

d. points b-c are repeated until sum of ΔE_{ij} corresponding to all merged pairs of segments is greater then T.

For triangularization of system in equation (11) a sequence of Givens rotations is used.

In the motion coefficient removal block the following strategy for coefficient removal is used:

a. a threshold T is selected which corresponds to allowed increase of square prediction error in whole frame.

b. for all segments and all basis functions q_i^2 is calculated using equation (16).

c. basis function of a segment with smallest q_i^2 is removed.

d. points b-c are repeated until sum of all q_i^2's corresponding to all removed basis functions in different segments is greater then T.

The system in formula (16) is triangularized using a sequence of Givens rotations.

The final motion coefficients of segments are calculated by solving equation (18) using backsubstitution algorithm.

The pixel values of $\tilde{I}_{n-1}(x,y)$, $G_x(x,y)$ and $G_y(x,y)$ are defined only for integer coordinates x and y. In many instances when x or y are noninteger the pixel value is calculated using bilinear interpolation of closest pixels with integer coordinates.

The system can be implemented in a variety of ways without departing from the spirit and scope of the invention. For instance, different linear motion models can be used in equations (3). Different methods can be used to linearize the term in the formula (5). Further, different criteria may be used to decided whether to merge or not to merge two segments. The strategy for deci-

ding whether a given basis function should be removed from the model may vary. Triangularization of matrices in equations (10) and (15) can be performed using various algorithms and calculation of final coefficients by solving equation (18) can be done using a number of known algorithms for solving systems of linear equations. Finally, different interpolation methods can be used to values of $\tilde{I}_{n-1}(x,y)$, $G_x(x,y)$ and $G_y(x,y)$ in noninteger coordinates.

We claim:

1. A video codec comprising:

a motion field coder responsive to the current frame, a reference frame and a motion vector field for producing a coded motion vector field and for minimizing the number of the motion coefficients,

the motion field coder comprising:

a first main block including linearization means for linearizing a squared error function between a segment of the current frame and a segment of the prediction frame, and matrix processing means for forming a first matrix $\mathbf{R}_i^1$ and a first vector $\mathbf{z}^1{}_i$, said matrix and vector being a new representation of the motion vector field of the segment;

a second main block connected to the first main block, the second main block including merging means for merging pairs of adjacent segments if the combined area can be predicted using a common motion field, wherein, for each merged segment, the block outputs a first merged matrix $\mathbf{R}^1{}_{ij}$ and a second merged vector $\mathbf{z}^1{}_{ij}$,

a third main block connected to the second main block, the third main block including coefficient removal means for removing motion coefficients of the segment untill the change of the squared prediction error is not acceptable, wherein the third main block outputs reduced number of motion coefficients of each segment.

wherein in the outputted coded motion vector field each motion vector is based on a linear motion model comprising basis functions and motion coefficients

2. A video codec as in claim 1, wherein linearization means transform the square prediction error to a form according to the formula:

$$\sum_{j=1}^{P}(e_{j,1}\tilde{c}_1 + e_{j,2}\tilde{c}_2 + \cdots + e_{j,N+M}\tilde{c}_{N+M} - y_j)^2$$

where c_i is motion coefficient and N+M is the number of motion coefficients.

3. A video codec as in claim 2, wherein the matrix processing means include means for constructing following matrices:

$$\mathbf{E}_i = \begin{bmatrix} e_{1,1} & e_{1,2} & \cdots & e_{1,N+M} \\ e_{2,1} & e_{2,2} & \cdots & e_{2,N+M} \\ \vdots & \vdots & \vdots & \vdots \\ e_{P,1} & e_{P,2} & \cdots & e_{P,N+M} \end{bmatrix}, \qquad \mathbf{y}_i = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_P \end{bmatrix}$$

4. A video codec as in claim 3, wherein the matrix processing means further include QR factorization means for decomposing in the as such known manner the matrix E_i into a product of a matrix Q_i and a matrix R_i and for forming an auxiliary vector z_i of the form $\mathbf{z}_i = \mathbf{Q}^T{}_i\mathbf{y}_i$ and for outputting a first matrix $\mathbf{R}_i^1$ consisting N+M first rows of matrix $\mathbf{R}_i$ and the first vector $\mathbf{z}^1{}_i$ consists of first N+M elements of $\mathbf{z}_i$.

5. A video codec as in claim 1, wherein the merging means includes means for triangularizating the linear equation

$$\begin{bmatrix} \mathbf{R}^1{}_i \\ \mathbf{R}^1{}_j \end{bmatrix} \mathbf{c}_{ij} = \begin{bmatrix} \mathbf{z}^1{}_i \\ \mathbf{z}^1{}_j \end{bmatrix}$$

where $\mathbf{R}^1{}_i$, $\mathbf{z}^1{}_i$ and $\mathbf{R}^1{}_j$, $\mathbf{z}^1{}_j$ are produced by the first main block for segments S_i and S_j respectively, to the form:

$$\begin{bmatrix} r_{1,1} & r_{1,2} & r_{1,3} & \cdots & r_{1,N+M} \\ 0 & r_{2,2} & r_{2,3} & \cdots & r_{2,N+M} \\ 0 & 0 & r_{3,3} & \cdots & r_{3,N+M} \\ 0 & 0 & 0 & \ddots & \vdots \\ 0 & 0 & 0 & 0 & r_{N+M,N+M} \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ \vdots \\ c_{N+M} \end{bmatrix} = \begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ \vdots \\ z_{N+M} \\ q_1 \\ q_2 \\ q_3 \\ \vdots \\ q_{N+M} \end{bmatrix}$$

6. A video codec as in claim 5, wherein the merging means further includes means for calculating the change of the square prediction error ΔE_{ij} in the area S_{ij} caused by merging of segments S_i and S_j in accordance with the following formula:

$$\Delta E_{ij} = \sum_{k=1}^{N+M} q^2{}_k$$

wherein the segments are merged if the change of the square prediction error is acceptable according to a given criterion.

7. A video codec as in claim 5, wherein the merging means further includes means for building for the resulting merged segment S_{ij} a matrix $\mathbf{R}^1{}_{ij}$ and a vector $\mathbf{z}^1{}_{ij}$ by taking first N+M rows of the triangularizated matrix equation, wherein the matrix $\mathbf{R}^1{}_{ij}$ and vector are described by the following formula:

$$\mathbf{R}^1{}_{ij} = \begin{bmatrix} r_{1,1} & r_{1,2} & r_{1,3} & \cdots & r_{1,N+M} \\ & r_{2,2} & r_{2,3} & \cdots & r_{2,N+M} \\ & & r_{3,3} & \cdots & r_{3,N+M} \\ & & & \ddots & \vdots \\ & & & & r_{N+M,N+M} \end{bmatrix}, \quad \mathbf{z}^1{}_{ij} = \begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ \vdots \\ z_{N+M} \end{bmatrix}$$

said matrix and vector being outputted from the second main block.

8. A video codec as in claim 1, wherein the merging information is send to the decoder.

9. A video codec as in claim 1, wherein the coefficient removal means includes means for reducing the matrix equation $\mathbf{R}^1{}_k \mathbf{c}_k = \mathbf{z}^1{}_k$ by removing i'th column from a matrix $\mathbf{R}^1{}_k$ and i'th element from the vector $\mathbf{c}_k$,

10. A video codec as in claim 9, wherein the coefficient removal means further includes means for triangularizing the reduced matrix equation to the form:

$$\begin{bmatrix} r_{1,1} & r_{1,2} & r_{1,3} & \cdots & r_{1,N+M-1} \\ 0 & r_{2,2} & r_{2,3} & \cdots & r_{2,N+M-1} \\ 0 & 0 & r_{3,3} & \cdots & r_{3,N+M-1} \\ 0 & 0 & 0 & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & r_{N+M-1,N+M-1} \\ 0 & 0 & 0 & \cdots & 0 \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ \vdots \\ c_{N+M-1} \end{bmatrix} = \begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ \vdots \\ z_{N+M-1} \\ q_i \end{bmatrix}$$

wherein the change of the square prediction error caused by removal of the i'th column and i'th element is equal to $q^2{}_i$.

11. A video codec as in claim 10, wherein the coefficient removal means further includes means for comparing the change of the prediction error to a chosen criterion.

12. A video codec as in claim 11, wherein the coefficient removal means further includes means for removing the motion coefficient c_i from the coefficient matrix if the change is acceptable, and means for forming a modified matrix $\mathbf{R}'_k$ and a modified vector $\mathbf{z}'_k$ by removing the bottom row from the triangularized matrix, said modified matrix and modified vector being applied to the coefficient removal means.

13. A video codec as in claim 11, wherein the coefficient removal means further includes means for calculating of final motion coefficients for the segment by solving the system of linear equations $\mathbf{R}'_k \mathbf{c}_k = \mathbf{z}'_k$, if the further change is not acceptable.

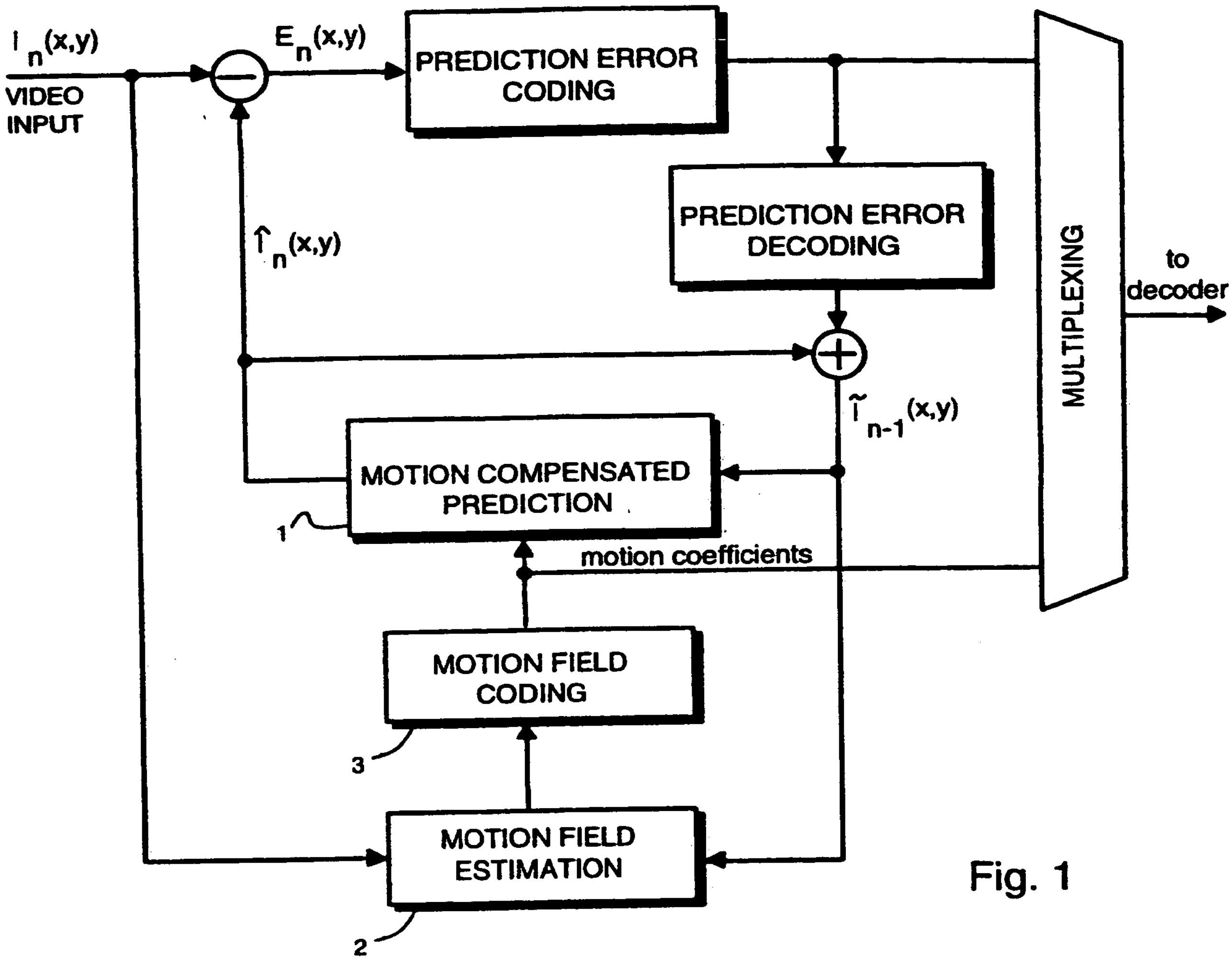
$I_n(x,y)$
VIDEO INPUT
$E_n(x,y)$
PREDICTION ERROR CODING
PREDICTION ERROR DECODING
$\hat{I}_n(x,y)$
$\tilde{I}_{n-1}(x,y)$
MOTION COMPENSATED PREDICTION
1
motion coefficients
MOTION FIELD CODING
3
MOTION FIELD ESTIMATION
2
MULTIPLEXING
to decoder

Fig. 1

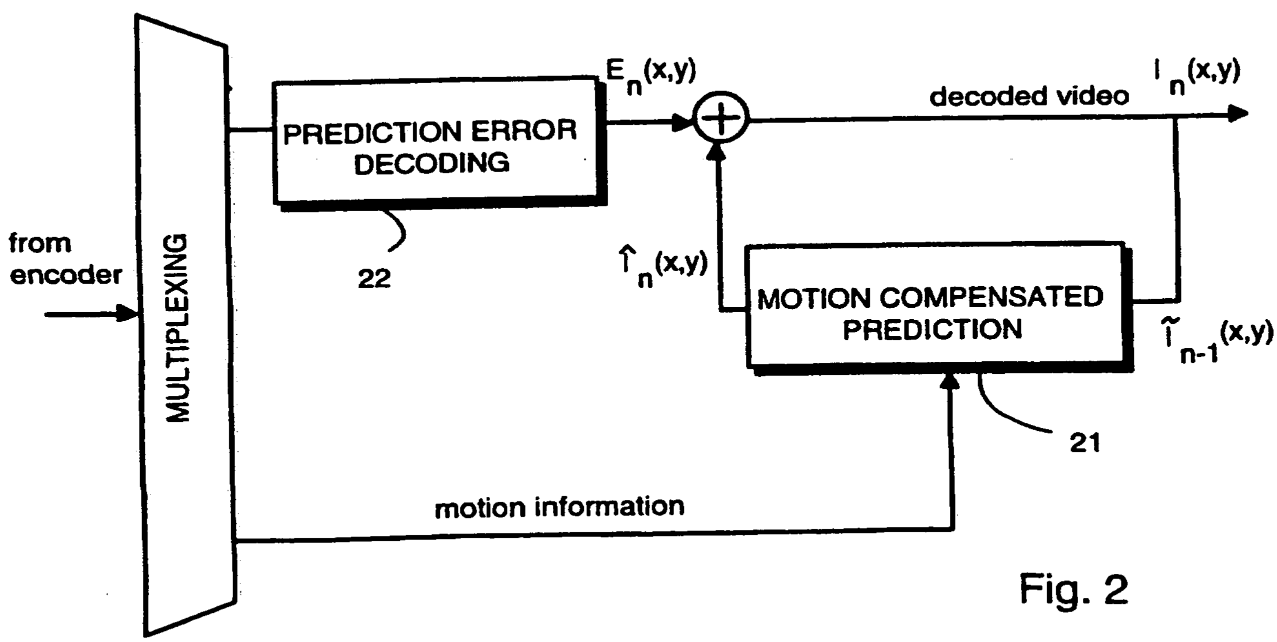
MULTIPLEXING
from encoder
PREDICTION ERROR DECODING
22
$E_n(x,y)$
decoded video
$I_n(x,y)$
$\hat{I}_n(x,y)$
MOTION COMPENSATED PREDICTION
$\tilde{I}_{n-1}(x,y)$
21
motion information

Fig. 2

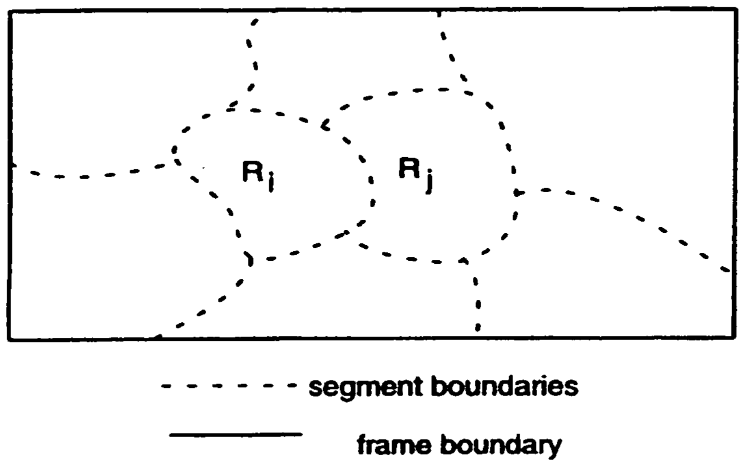
R_i
R_j
segment boundaries
frame boundary

Fig. 3

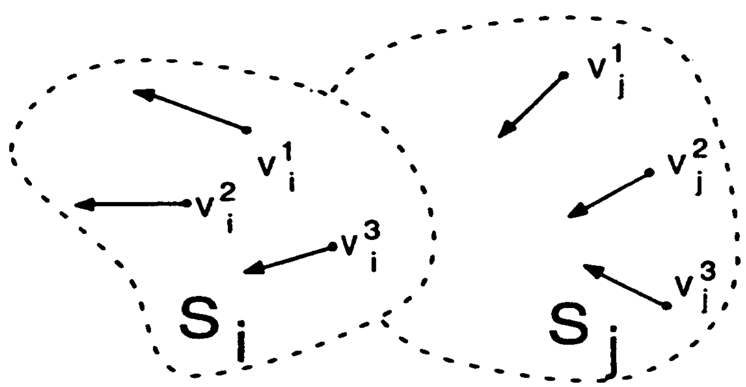
v_i^1
v_i^2
v_i^3
S_i
v_j^1
v_j^2
v_j^3
S_j

Fig. 4

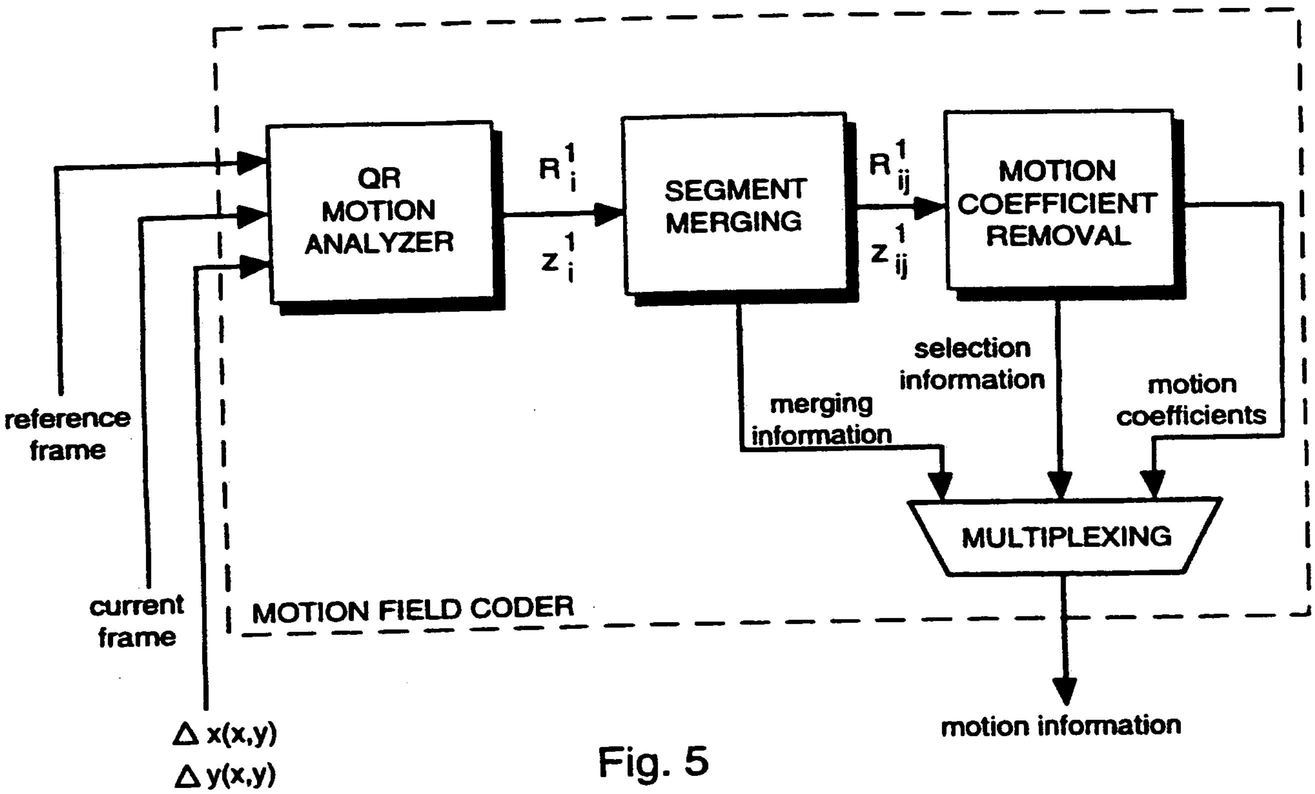
QR MOTION ANALYZER
R_i^1
z_i^1
SEGMENT MERGING
R_{ij}^1
z_{ij}^1
MOTION COEFFICIENT REMOVAL
selection information
merging information
motion coefficients
MULTIPLEXING
reference frame
current frame
MOTION FIELD CODER
$\Delta x(x,y)$
$\Delta y(x,y)$
motion information

Fig. 5

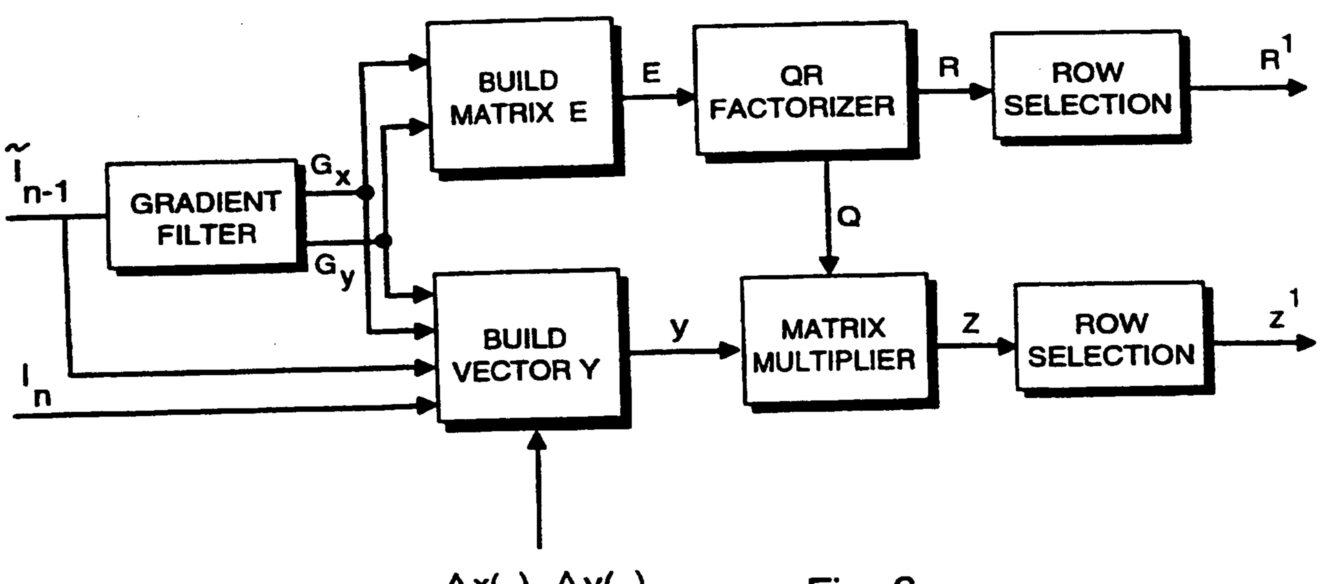
$\tilde{I}_{n-1}$
GRADIENT FILTER
G_x
G_y
BUILD MATRIX E
E
QR FACTORIZER
R
ROW SELECTION
R^1
Q
BUILD VECTOR Y
y
MATRIX MULTIPLIER
z
ROW SELECTION
z^1
I_n
$\Delta x(\ ), \Delta y(\ )$

Fig. 6

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	INTERNATIONAL SYMPOSIUM ON FIBER OPTIC NETWORKS AND VIDEO - PROCEEDINGS OF THE SPIE , vol. 1977, April 1993, pages 276-287, XP000571199 C.STILLER ET AL.: "Combined Displacement Estimation and Segmentation in Image Sequences"	
A	FR,A,2 628 864 (L'ETAT FRANCAIS ET AL.) 22 September 1989	
A	DE,A,41 38 517 (UNIVERSITÄT HANNOVER) 27 May 1993	

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/FI 95/00581

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
FR-A-2628864	22-09-89	NONE	
DE-A-4138517	27-05-93	NONE	

INTERNATIONAL SEARCH REPORT

International Application No
PCT/FI 95/00581

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04N7/26

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	VISUAL COMMUNICATIONS AND IMAGE PROCESSING '95 - PROCEEDINGS OF THE SPIE , vol. 2501, no. 2, 24 - 26 May 1995, USA, pages 787-798, XP000570941 T.EBRAHIMI ET AL.: "Joint Motion Estimation and Segmentation for Very Low Bit Rate Video Coding" see the whole document --- -/--	1-13

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

2

Date of the actual completion of the international search	Date of mailing of the international search report
21 May 1996	04.07.96

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	Giannotti, P

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	VISUAL COMMUNICATION AND IMAGE PROCESSING '91: VISUAL COMMUNICATION, BOSTON, NOV. 11 - 13, 1991, vol. 1605 PART 2/02, 11 November 1991, KOU-HU TZOU;TOSHIO KOGA, pages 697-708, XP000479277 LABIT C ET AL: "COMPACT MOTION REPRESENTATION BASED ON GLOBAL FEATURES FOR SEMANTIC IMAGE SEQUENCE CODING" see the whole document ---	1-13
A	IEEE TRANSACTIONS ON IMAGE PROCESSING, vol. 4, no. 9, September 1995, NEW YORK US, pages 1223-1235, XP000533955 H.ZHENG ET AL.: "Motion-Based Object Segmentation and Estimation Using the MDL Principle" see abstract ---	1
A	VISUAL COMMUNICATIONS AND IMAGE PROCESSING '95 - PROCEEDINGS OF THE SPIE, vol. 2501, no. 3, 24 - 26 May 1995, USA, pages 1442-1452, XP000570936 L.WU ET AL. : "Region-Based Time-Varying Image Coding at low bit-rate with a high visual quality" see abstract; figure 1 ---	1
A	PROCEEDINGS OF THE PICTURE CODING SYMPOSIUM (PCS), LAUSANNE, MAR. 17 - 19, 1993, no. -, 17 March 1993, SWISS FEDERAL INSTITUTE OF TECHNOLOGY, pages 4.4/A-4.4/B, XP000346252 SANSON H: "REGION BASED MOTION ESTIMATION AND COMPENSATION FOR DIGITAL TV SEQUENCE CODING" ---	
A	PROCEEDINGS OF THE PICTURE CODING SYMPOSIUM (PCS), LAUSANNE, MAR. 17 - 19, 1993, no. -, 17 March 1993, SWISS FEDERAL INSTITUTE OF TECHNOLOGY, pages 4.5/A-4.5/B, XP000346253 WAGNER P ET AL: "REGION-BASED MOTION FIELD ESTIMATION" ---	

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2